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ABSTRACT

A program of research was conducted to study transitions from preoperational to concrete operational forms of spatial imagery (area 1), to compare results from spatial imagery studies based on open-ended measures (such as drawings) with results based on reaction time measures (area 2), and to study anticipatory imagery in the contexts of memory and problem-formulative anticipation (area 3). Research in area 1 tested three predictions, generated from a revision of Piagetian theory, concerning children's performances on two anticipatory imagery tasks and a standard conservation task. Discussion in area 2 reports results of a study testing the hypothesis that drawing errors on anticipatory kinetic imagery tasks reflect children's poor images of objects in anticipated states of movement. Also reviewed is a study comparing preschool and older children's abilities to mentally track an object through a rotation movement, as well as further investigations addressing questions of developmental differences under certain task conditions, age differences in mental tracking strategies, and the relationships of strategies to tracking rates. Research in area 3 investigates whether children mentally transform object states on tasks in which particular processing strategies are unspecified and examines the effect of transforming strategies on short-term and long-term memory for figurative states. Related materials are appended. (RH)

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Final Report

The Development and Function of Children's Spatial Imagery

NIE-G-79-0092

Principal Investigator

Anne L. Dean

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Table of Contents

		page
I.	Objectives	1
II.	Transitions in the development of spatial imagery	1
	A. Children's precocious anticipatory images of end-states	3
III.	Analyses of children's spatial imaging capacities using reaction-time measurements and comparisons of RT with drawing measures.	6
	A. A comparison of RT and drawing measures of mental rotation	7
	B. The development of children's mental tracking strategies on a rotation task (Dean, Duhe & Green 1982)	11
IV.	Children's spontaneous transformational imagery and memory for figurative states	18
V.	Appendices	

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I. Objectives

The objectives of the research conducted under the auspices of this grant were to study transitions from pre-operational to concrete operational forms of spatial imagery, to compare results from spatial imagery studies based on open-ended measures such as drawings with results based on reaction-time-measures, and to study anticipatory imagery in the contexts of memory and problem-formulative anticipation. Background information and data presentations in this report are organized around these three objectives.

II. Transitions in the development of spatial imagery.

In Piagetian research, tasks in which children judge a transformation performed by an experimenter (e.g. conservation tasks) or manipulate objects to obtain a given result (e.g. seriation, classification, measurement tasks, etc.) are designated "operations" tasks, and are presumed to measure the structure of children's knowledge in a given domain. For example, children who judge that the length of a stick becomes longer after it is displaced from left to right are said to use one-way, or irreversible logic, since their judgment suggests a lack of understanding of compensatory or inverse relations between the starting and end-state of the displacement. A second type of task used in Piagetian research has been designated an "imaging" task (Piaget & Inhelder 1971) and requires children to mentally construct a stipulated sequence of actions on an object(s). For example, children might be asked to imagine how a stick would appear during and after its displacement from left to right. InPiaget and Inhelder's (1971) view, imaging tasks differ from operations tasks primarily in the degree to which mental anticipation is required, but are similar to each other in the structure of knowledge required to achieve a correct solution. In the example of the displaced stick, Piaget and Inhelder's hypothesis is that an accurate image of the displacement depends on children's knowledge of compensatory relations between spaces vacated and newly occupied by the moving stick. Support for this hypothesis has been provided in studies showing that non-conserving children typically represent a change in the stick's length in their images of the displacement, while conservers maintain the stick's length while representing changes in its position (Dean 1976; 1979a; Piaget & Inhelder 1971; Youniss & Dean 1974).

A review of findings from Piagetian imagery studies suggests the following developmental progression. Children younger than roughly five or six years of age (with ages varying depending on the task and characteristics of the subject population are typically unable to predict the form of movements, transformation or their end-states. The label that has been given to children's imagery at this level is "static" (Piaget & Inhelder 1971), although it is not the case that no change is reflected. On the contrary, "static" images most typically reveal "maintaining" errors (DeLisi, Locker & Youniss 1976; DeLisi & McGillicuddy-DeLisi, note #2), in which some features of initial states that should be changed in the transformation are maintained, while others features that should

be maintained are changed. A maintaining error in the preceding conservation of length example is failing to change the position of one end of the stick while changing the position of the other end, and in the process, changing the stick's length. Maintaining errors arefound predominantly in the imaginal productions of children using preoperatory reasoning on operations tasks (Dean 1976, 1979a; Piaget and Inhelder 1971; Youniss and Dean 1974). This relation between children's pre-operational reasoning and maintaining errors in imagery has been observed both when the structure of children's imagery has been analyzed (Dean 1976; Piaget and Inhelder 1971) and when children's imaging processes or strategies have been measured (Dean 1979b; McGillicuddy-DeLisi and DeLisi 1977).

Developmental improvements occur first in the spatial concept domain as children begin to apply reversible logic in judging transformations on operations tasks. These changes are followed by a restructuring of children's imagery. Maintaining errors no longer occur, and children can construct sequences of intervening and end-states defining movements and transformations (Dean 1976, 1979a; Piaget and Inhelder, 1971).

Piaget and Inhelder have admitted that there are problems with this proposed sequence. A major problem is that in some experiments in their research, children have correctly imagined end-states of stipulated action sequences without apparent understanding or ability to imagine the form of the action sequence itself. Similar types of imaging performances were observed in Dean (1976) and Youniss and Dean (1974). One example of "state-to-state" imagery is children's performances on Piaget and Inhelder's wire arc transformation task. Some children maintained the original length of the arc's chord throughout their drawings of a series of progressively flattening intervening states, but drew the length of the wire in its straight-line end-state correctly. Since Piaget and Inhelder (1971) have proposed that children's imaginal constructions of end-states derive from transforming processes based on knowledge of spatial relationships, it is not clear from their position how end-state images are derived apart from these transforming processes.

Piaget and Inhelder have argued that "state-to-state" images do not constitute true imaginal changes of state, but are reproductions of static configurations experienced by children in their daily lives. Further, they have asserted that end-state images do not lead to a better understanding of the preceding action sequence, since children who generage correct end-states images still do not understand the transformation.

The second of these arguments is circular, while the first is inconsistent with Piaget and Inhelder's (1973) own position regarding children's memory for static configurations. In this view, even memory for static states is influenced by the child's level of understanding of the transformations that produce the states. For instance, children's reproductions of an ordered series of sticks varied depending upon their own methods of seriating sticks. In sum, the phenomenon of state-to-state imagery is inconsistent with Piaget and Inhelder's position regarding the developmental basis of imagery development, and their alternative explanations seem inadequate for reconciling the phenomenon of state-to-state imaging with their position.

This inconsistency between observed "state-to-state" images and Piaget and Inhelder's argument that true end-state images depend on understanding of and imaginal production of preceding states could be resolved if state-to-state imagery were shown to be a manifestation of children's operatory intelligence in the transition between the pre-operational and concrete operational periods. Several researchers in fact, have concluded that one characteristic of children's thought in the transitional period is the ability to make accurate inferences or predictions on the basis of correspondences between states, rather than on the basis of the transformation of one state into another. Gelman (1978), for example, reported that preschoolers can sometimes arrive at a correct solution to a number conservation task by counting the numbers of objects in each set before and after a spatial transformation of one set. This contrasts with the typical behavior of older children who reason on the basis of the transformation. Brown and French (1976) reported that children given the beginning of a narrative story can often provide a reasonable conclusion but have more trouble supplying causes for outcomes, a task which presupposes an understanding of the transformation itself. Youniss and Dennison (1971), demonstrated that some children can make correct inferences about size relations on the basis of figurative cues associated with the terms to-be-compared, but not on the basis of a common middle term which would require reversible logic. A stress on the functional role of state-to-state reasoning in the development of subsequent cognitive transformations was in fact implied by Piaget in a statement regarding the development of conservation concepts: ("The child) must first discover the correspondence between two states in order to make comparisons, and this has to precede any transformations, any working of changes on these fixed states" (Piaget 1975, cited in Gelman 1978, p. 302).

A. Children's precocious anticipatory images of end-states.

Piaget's revised theory makes three predictions about children's performances on anticipatory imagery tasks. The first is that some children will use a figurative matching process to construct anticipated end states of movements. The second is that these children will be intermediate in age between those who anticipate end states by imaging a prior movement and those who are unable to anticipate end states. This prediction follows from Piaget's supposition that figural construction of end states constitutes a necessary precursor of operational state construction. The third is that accurate judgments on a conservation task will be made both by children who imagine movements and children who construct end states by a figurative matching process, but that incorrect judgments will be made by children who are unable to anticipate end states of movements. This prediction follows from Piaget's hypothesis that children can both anticipate the end states of a movement and evaluate the equivalence of objects in a movement's end state by either a figurative matching process or by operational deduction.

The present study tested these predictions on two anticipatory, imagery tasks and a standard conservation task. On a recognition imaging task, children evaluated films on the basis of whether they accurately depicted the left-

to-right-transposition movement of a stick. Incorrect films showed the stick changing length during movement and either ending a different length than in the starting state or ending the same length as in the starting state (-I-E, and -I+E). On a production imaging task, children manipulated slats in opposite sides of a board that controlled the length and position of a black strip exposed to view. The strip was described as representing an actual black stick. On different trials, children were told to (a) make the black "stick" get longer (or shorter), (b) show how the black stick would look after it moved to the right, or (c) show how the black stick would look while it was moving.

Three patterns of performance on the two imaging tasks were predicted. (a) The most primitive pattern was expected to reflect some children's conceptual understanding of movement as a change in the order of an object's end points (Piaget, Inhelder, & Szeminska 1960). Since all films on the recognition task showed such a change, it was anticipated that these children would judge all films as correct instances of a "movement." A comparable performance on the production task would be to respond to all three sets of instructions by changing the length of the stick. (b) The second predicted pattern was derived from the hypothesis that some children anticipate end states of movements by a figurative matching process. On the recognition task, it was expected that these children would judge as correct all films showing sticks with equivalent lengths in the starting and end states. On the production task, it was expected that these children would accurately construct the stick in a new end-state position by successively adjusting the slats until the strip was the same length as in the initial state. (c) The developmentally most advanced pattern was predicated on the hypothesis that some children anticipate end states as the direct outcome of a movement. These children were expected to judge as correct only films showing the stick's length maintained throughout the movement on the recognition task and to coordinate manipulations of opposing slats on the production task to represent the movement of the black stick.

A total of 65 Caucasian middle-class boys and girls attending a summer day camp in New Orleans, Louisiana, were tested. They ranged in age from 4-6 to 7-8 years.

The data from this study supported Piaget's (1977) hypothesis that some children imagine end states of movement by mentally constructing an object which corresponds figuratively to the same object in its initial state. Indirect evidence for the hypothesis was provided by children's judgments on the recognition-imaging task. On this task, a group of children said that films showing a stick increasing and decreasing in length as it moved, but ending the same length as in the initial state, correctly represented the transverse movement of a real stick. Conversely, they said that films ending longer or shorter in the final state of movement did not correctly show how a real stick would look when it moved. These judgments indicate that the primary basis for their evaluation was the appearance of the stick in the end state, rather than the form of the preceding movement.

More direct evidence for the figurative matching process was obtained on the production imaging task. Children performing on this task had to move

slats at opposite sides of a board that controlled the amount of black strip exposed to view. The strip represented a real cardboard stick used in a preliminary phase of the study. When the movements of both slats were coordinated--that is, when both slats were moved simultaneously in the same direction at the same speed--an impression of a transverse movement in the black stick was created. However, when children who judged films on the recognition task by the quality of the depicted end state were instructed to represent a movement of the black stick on the production task, they moved the two slats one at a time until the board showed a black stick in a new location that corresponded in length to the original black stick. The correspondence between children's responses to instructions to show a movement and to show an end state suggests that the two sets of instructions were interpreted synonymously. Both movement and end states were constructed by a process of successive slat adjustments that achieved a figurative correspondence between the stick in its initial and final state positions. These children's performances on the production imaging task thus corroborated the interpretation of their recognition task performances.

The prediction that children who used a figurative matching process to compare and produce end states of movement would be midway in age between those who used an operational process and those could use neither process was supported by the finding of a significant correlation between children's ages and imaging task performances. Although there was overlap among the ages of children in the three imaging task performance groups, children who on the average were the oldest in the sample evaluated films on the basis of the quality of the depicted movement on the production task and coordinated the movement of the opposing slats to show a moving stick. Children who were the youngest said that sticks becoming and ending longer (or shorter) in the films represented the movement of a real stick and actually lengthened or shortened the stick in movement, end-state, and length-change conditions of the production task.

The third prediction from Piaget's (1977) theory was that correct conservation of length judgments would be made by children who could use either a figurative matching or operational construction process for imaging anticipated end states. This prediction followed from Piaget's supposition that figurative matching is a process that can be used effectively in comparing initial and final states in a standard length-conservation task. Chi-square analyses of the relation between judgment and imaging task performances supported this prediction. An additional indication that children used different processes for making correct decisions on the conservation task was their explanations. Children who used a figurative matching process on imaging tasks predominantly said that the transposed stick's length was conserved because "You moved it" or because "They look the same" (referring to the stick's relation to the stationary stick). In contrast, children who correctly evaluated and produced movement on imaging tasks gave explanations like "Both ends moved together" or "Cardboard doesn't stretch like a rubber band." Although comprehensible explanations could be elicited from only 67% of children who made correct conservation judgments, these examples suggest that children in the more advanced imaging group were considering critical properties of the stick's movement

or physical properties of the stick as they might be affected by movement, while children at the intermediate level were invoking perceptual reasons or simply restating the fact of the stick's movement.

The argument thus far has been that children's performances on the recognition and production imaging tasks reflect their conceptual understanding of movement. However, there are three alternative explanations for younger children's performances on the production task that should be considered. One is that children in group III thought they were supposed to produce an actual movement of a slat on the board, rather than an apparent movement of the black stick. This explanation, however, is inconsistent with the finding that group III children's strategies when instructed to produce a length change were identical with their strategies when instructed to produce a movement or an end state. It is also inconsistent with the finding that group III children's performances on the production task corresponded qualitatively to their performances on the recognition task. The second explanation is that younger children were too motorically inept to coordinate the simultaneous movement of two slats required to represent "movement." However, 25% of group III and 30% of group II children used a simultaneous-move strategy in the length-change condition. Finally, it might be argued that younger children were simply playing with the board, rather than moving slats strategically. However, the finding that a high percentage of children in both younger groups used the same strategy on three out of four trials in a condition clearly argues against this explanation. In short, none of the three alternative explanations is supported by the data.

The finding that children can use qualitatively different processes to arrive at correct solutions to problems is not without precedent in the cognitive developmental literature. For example, figurative and operational solutions have been demonstrated on number conservation (Gelman 1978), temporal ordering (Brown & French 1976), transitive inference (Youniss & Dennison 1971), and class inclusion (Dean, Bridges, & Chabaud, 1981) problems. Whether figurative solutions to these problems are necessary prerequisites for the development of operation solutions may not be demonstrable by available developmental research techniques (McCall 1977). The range of tasks in which figurative and operational solutions have been demonstrated, however, does suggest that the figurative matching process may be a general characteristic of children's thinking in the transition from preoperational to concrete operational stages.

III. Analyses of children's spatial imaging capacities using reaction-time measurements and comparisons of RT with drawing measures

Mental images, by definition, are internal, unobservable psychological phenomena. Thus, the quality of a person's imagery must be inferred from observable behaviors which are assumed to be associated with the imaging process. In the cognitive developmental literature, a controversial issue concerns the validity of children's drawings as measures of their imagery of spatial transformations and movements. In Piaget and Inhelder's (1971) research and other Piagetian imagery studies (Dean 1976; 1979a; Youniss & Dean 1974), drawings were the basis for the description of devel-

opments in the quality of children's imagery from the pre-school through the adolescent years. Drawings made by the younger children -- i.e. 5 and 6 year olds-- were "static" in that objects or parts of objects were represented in anticipated future states as they appeared in the initial state. The average age at which older children could correctly draw moving objects depended on the nature of the movement and the figural complexity of the intervening and final states. For example, transposing objects were easier to draw than rotating objects, and objects moving in relation to a stationary frame of reference were easier to draw than objects moving in relation to a moving reference frame. Objects which moved through an empty field were easier to draw than objects which intersected other objects during movement, and objects oriented vertically or horizontally in relation to a reference frame were easier to draw than obliquely oriented objects (Dean 1976; Piaget 1970; Piaget & Inhelder 1971; Piaget, Inhelder & Szeminska 1960). Piaget and Inhelder interpreted errors in children's drawings as indicative of poor mental images, and hypothesized that poor images stemmed from children's inabilities to conceptualize external spatial reference systems and the logical properties of object displacements within reference systems.

Skepticism about children's drawings come primarily from researchers of an information-processing theoretical bent, who prefer to study children's rotation using a reaction-time procedure (Childs & Polich 1979; Kail, Palligrino & Carter 1980; Marmor 1975; 1977). The procedure is based on Shepard's (Cooper & Shepard 1973; Shepard & Metzler 1971) methods for studying adult's mental rotation. Subjects are instructed to prepare an image of an object in anticipated states of rotation, and then to compare their image with an external standard. Mental rotation is inferred if preparation times increase as a linear function of degree of rotation, if decision times are uniformly fast across orientation, and if subjects are accurate in comparing their prepared images with the standard (Cooper & Shepard 1973). The results from these studies generally complement Piaget and Inhelder's (1971) findings by showing that children 8 years of age and older can mentally rotate, become more accurate and efficient at rotation (Kail et al 1980; Marmor 1975; 1977) and faster in their response times (Childs & Polich 1979) as they grow older. However, Marmor's finding that 4 and 5 year olds can mentally rotate contradicts Piaget and Inhelder's results. Her explanation for the difference was that errors in younger children's drawings on Piagetian tasks probably reflect their poor motor coordination. In a similar vein, Kosslyn (1980) claimed that errors in children's drawings might simply be conventions that the child uses to externalize internal events onto two-dimensional surfaces. In Kosslyn's words, "a child's image might be perfect, but his or her drawings skills limited" (Kosslyn 1980, 420-421). Both critics, therefore, rejected Piaget and Inhelder's assumption that children's drawing errors reveal the inadequacy of their mental images, and thus discounted the contributions of Piagetian research for an understanding of imagery development.

A. A comparison of RT and drawing measures of mental rotation

This study tested the hypothesis that drawing errors on anticipatory kinetic imagery tasks reflect children's poor images of objects in anticipated states of

movement. The hypothesis was tested by comparing children's performances on a RT version and a drawing version of Piaget and Inhelder's (1971) rotating squares task. If error patterns in children's drawings are consistent with RT task data interpretations of children's imaging abilities, then it can be concluded that drawing errors reflect the quality of children's mental imagery. In contrast, if the patterns and qualities of children's drawing errors are unrelated to their RT task performances, then a case can be made for Kosslyn's and Marmor's claims that drawing errors result solely from children's conventions or poor motor coordination.

The rotating squares task, as administered in Piaget and Inhelder's research, required children to imagine a square rotate around a pin which joined the square to a second, stationary square. The stationary square was in a vertical-horizontal (V-H) orientation relative to the backdrop. In an actual physical rotation, the squares assume different configurations depending on the rotating square's orientation and position relative to the stationary square. In some states, the rotating square is oriented obliquely and partially overlaps the stationary square. In other states, the rotating square is in a V-H orientation, and is either juxtaposed next to the stationary square, or covers the stationary square. Piaget and Inhelder concluded that 10 and 11 year olds in their sample could imagine a rotation movement, since they were able to draw the squares correctly in both oblique and V-H orientations. In contrast, 7 to 9 year olds were described as capable of imagining the square's displacement as a "position change" but not as a "distance covered, with its various characteristics -- direction, measurable size, shape and orientation..." (Piaget and Inhelder 1971, p. 139), since they were able to draw the squares correctly in some V-H orientations, but systematically distorted the squares shape and pivot position in oblique orientations. In Piaget and Inhelder's interpretation, images of position changes only require knowledge of simple ordinal operations, while images of displacements as "distance covered" require knowledge of coordinate axis reference systems. Five and 6 year olds indicated an inability to imagine even simple position changes, since they either represented no change in the square's position or orientation, elongated the square, or moved both squares simultaneously, thus conserving the initial configuration. These errors resulted in low percentages of correct drawings at both V-H and oblique orientations.

Based on Piaget and Inhelder's results and interpretations, the data analyses for both the RT and drawings tasks in this study compared V-H and oblique orientations. First, it was predicted that children classified as "mental rotaters" on the RT task would draw both oblique and V-H states correctly. Second. it was predicted that some children would respond more quickly and make more accurate decisions on V-H than oblique angle trials on the RT task, and would also draw the squares more accurately in V-H than oblique orientations. Finally, it was predicted that some children would perform equally poorly on oblique and V-H angle trials, on both the RT and drawing tasks.

Forty-eight white, middle and lower-middle class girls attending parochial and public elementary schools in New Orleans, La. were tested. Four children were dropped from the study because of inattentiveness during the

reaction-time task. The ages of the remaining 44 children ranged between 5.6 and 13.8 years, with a mean of 9.2 and a standard deviation of 1.9 years.

Children's preparation and decision phase performances of the RT task suggested that nine children mentally rotated in the preparation phase (group A); nine children imagined some change in the square's position, since preparation times differed as a function of V-H and oblique orientations, but did not succeed in preparing an image by mental rotation (group B); and 26 children used no discernable systematic strategy (group C).

An analysis of variance performed on children's ages indicated that there were no significant differences between groups A, B, and C, $F(2,41) = 1.86$, $p > .05$. Children in group A were between 7.5 and 12.3 years, with eight of the nine children between 9.9 and 12.3 years. The mean for the total group was 10.3. Children in group B were between 6.8 and 12.4 years, with a mean of 9.1 years. Children in group C were between 5.6 and 13.8 years, with a mean of 8.9 years.

Children's performances on the drawing task were analyzed according to the quantity and quality of errors in their drawings of the squares at each of the four rotated orientations. All of the children drew the 0^{o} orientation correctly. Table 2 shows the percentages of children in the three reaction-time task groups who were correct in drawings of the four rotated orientations, and the percentages of children with four performance patterns; (a) no correct drawings; (b) at least one correct V-H drawing, but not correct oblique drawings; (c) at least one correct V-H and at least one correct oblique drawing, but not all correct; and (d) all correct. Reaction-time task groups were differentiated on both measures. Children in group A were more accurate overall than children in groups B or C. Error patterns indicated that group A children's difficulty was with "far" orientations, rather than with oblique states per se. The percentages of correct drawings for these children were high for the two near orientations (45^{o}, 90^{o}), but only moderately so for the two far orientations (135^{o}, 180^{o}). All of the children in group A drew at least one V-H and one oblique angle orientation correctly (performance patterns (c) and (d)).

Children in group B were mid-way between groups A and C in overall accuracy. Their greatest difficulty was clearly with oblique orientations. In comparison to group A, children in group B made almost as many correct drawings of V-H states, but fewer correct drawings of oblique states. Their individual performance patterns were predominantly of the second type (pattern b) -- i.e. no correct oblique states, but at least one correct V-H state. Finally, children in group C made the lowest percentage of correct drawings on all four states. Their predominant pattern was no correct drawing (pattern c).

An analysis of variance was performed on the number of correct drawings made by children in the three groups at the two combined oblique orientations and the two combined V-H orientations. Both the groups, $F(2,41) = 16.72$, $p < .001$, and the orientations, $F(1,41) = 11.68$, $p < .001$ main ef-

fects were significant. A chi square analysis performed on the frequencies of children in groups A, B, and C with individual performance patterns of types (a), (b), and combined (c) and (d) indicated that the relationship was highly significant, $X^2(4) = 34.53$, $p < .001$.

There were three categories of children's incorrect drawings. In the first, (incorrect change), children drew the squares correctly with respect to all aspects except orientation. Both of the squares were represented in approximately square shapes, the two connected corners were together, and the top square was rotated but to the wrong orientation. In the second (static), were drawings in which the squares appeared exactly the same as in the starting state, in all stipulated orientations. This description fits all types of drawings in this category precisely, with two exceptions. One type included drawings in which the only change was in the orientation of the arrow drawn on the top square. Children were not instructed to draw the arrow, but sometimes did so voluntarily, most often in drawings in this category. The second type included drawings in which children only changed the position of the pivot.

In the third category (maintaining) were drawings of various types, all of which had in common the feature that an aspect of the squares that should have been changed was maintained, whereas an aspect that should have been maintained was changed. Most often, the aspects maintained incorrectly were the initial non-overlapping positions of the two squares, and the verticality or horizontality of some of the sides of the rotating square. In order to maintain these aspects, children most often changed the pivot position and/or shape of the rotating square. Children in group C most often made static errors, children in group B most often made maintaining errors, and children in group A, the same number of maintaining as incorrect change errors. Kruskal-Wallis tests were used to compare the numbers of drawings made by children in the three groups, for each of the error categories separately. The results indicated a significant group difference for the static error category, $\underline{H} = 25.11$, $df = 2$, $p < .001$; and for the maintain error category, $\underline{H} = 8.37$, $df = 2$, $p < .02$, but not in the incorrect change category.

In summary, reaction-time and drawing measures of children's mental rotation suggested similar qualities of imaging. For group A, both measures indicated that children could imagine the square's rotation. Group A children were prepared to make fast and accurate decisions in both conditions of the RT task, and were able to draw the squares in both anticipated oblique and V-H orientations.

For group B, both measures indicated that children did not mentally rotate. They were not prepared to make fast or accurate decisions in either decision phase condition on the RT task, and their drawings failed to conserve aspects of the square that remain invariant during a rotation movement -- i.e. the pivot position and the square's shape. Both measures indicated, however, that group B children could imagine some change, and that the differences in the squares' configuration in different states of rotation played a significant role in children's ability to imagine change. On both measures, children found it easier to imagine the square in anticipated

V-H than anticipated oblique orientations.

Finally, both measures suggested that children in group C could not reliably imagine change to any orientation. On the RT task, children's response times and error rates failed to differentiate among orientations. Their drawings showed little or no change from the initial perceptible state.

One explanation for the correlation between children's performances on the drawing and reaction-time tasks in this study could be that children improve in both their drawing skills and mental representations as they grow older, but that these developments are parallel and independent. The adequacy of this explanation was tested by two analyses. The first was a partial correlation between children's reaction-time task groups and their total number of errors at the four rotated orientations, with age controlled, $r = .64$, $p < .001$. The other was a 3(groups) X 2(orientations) analysis of variance performed on the numbers of children's drawing errors at oblique and V-H orientations, with age as a covariate. The groups main effect was significant, $F(2,40) = 14.73$, $p < .001$. Age, therefore, was not the sole contributing factor to the observed relationship between children's reaction-time task and drawing task performances.

B. The development of children's mental tracking strategies on a rotation task (Dean, Duhe and Green 1982).

The results of Marmor's (1975; 1977) studies also differ from the results of two studies by Dean (Dean & Harvey 1981; Dean & Scherzer 1981) in which Marmor's rotation paradigm was used to investigate children's performances on Piaget and Inhelder's (1971) rotating squares task. In these two studies, some 7 and 8 year olds generated linearly increased reaction times, but younger children did not.

The primary difference between Dean's and Marmor's studies was in the nature of their respective stimuli (squares vs. bears). There are two ways in which bears differ from squares which may account for pre-school children's relatively better performanc-s on Marmor's task. A bear's torso supports its head, its legs support its torso, and so on. Pre-school children's familiarity with these functional relationships may held them conserve the spatial relations among the bear's parts during mental rotation. In contrast, a square is an abstract figure defined exclusively by spatial relationships. A square's sides are of equal length, and its angles are 90°. Pre-school children typically do not understand that metric properties of objects are conserved when they are moved (Piaget, Inhelder & Szeminska 1960), and thus have difficulty maintaining these properties in their images of objects undergoing movement (Dean 1976; 1979; Piaget & Inhelder 1971).

Second, the parts of a bear are figuratively distinct, while a square's parts are figuratively redundant. Distinctive parts of objects may provide cues for accurate same-different judgments on a Shepard-Metzler task based on a non-rotational strategy (Cooper & Shepard 1973; Cooper & Podgorny 1976; Kosslyn 1980). For example, in Marmor's studies, children may have perceptually

searched for corresponding arms on the two bears and then decided if they were both oriented in the same direction in relation to the bear's body. Or, children may have referenced the bear's arm to a part of their own bodies, and then turned their bodies, in the direction indicated by the comparison bear's orientation. This latter strategy could be used whether the two bears were presented simultaneously, as in Marmor's studies, or successively. Thus, the dilemma posed by the Shepard-Metzler task when used with pre-school children is that stimuli designed to facilitate the maintenance of spatial relations among object parts during mental rotation can also provide opportunities for children to make correct same-different judgments using non-rotational strategies that are indistinguishable on reaction-time measures from rotational strategies.

The purpose of experiment 1 was to compare pre-school and older children's abilities to mentally track an object through a rotation movement. A procedure was used in which children were explicitly told to imagine a pointer, resembling the hand of a clock, rotating in a clockwise direction at the same, self-chosen speed on every trial. When 3,4,5,6, or 7 seconds had elapsed after the beginning of a given trial, the experimenter gave a signal. The child's task was to indicate the location on the backdrop that marked the pointer's imagined position at the time of the signal.

The procedure differed from the Shepard-Metzler procedure in three ways which aided in the unambiguous interpretation of results. First, in the Shepard-Metzler procedure, mental tracking was a means by which children could achieve the primary stated goal of the task, which was to discriminate same from different pairs of stimuli. Thus, children could have chosen alternative methods for making same-differnet discriminations, and still have met the task's stated objective. In the present experiment, the primary stated goal was to keep track of the pointer's rotation so that its location could be specified at any point in time. Thus, children who mentally track the pointer failed to meet the stated objective.

Second, Shepard and his associates (Cooper & Shepard 1973) have admitted that linear components of reaction-time functions are not essential to infer mental rotation on same-different comparison tasks. For example, in cases where stimuli are highly familiar, comparisons between differently oriented stimuli could be made without rotation at small degrees of angular disparity, but require rotation at larger degrees of angular disparity. Thus, curvilinear reaction time functions could be generated by mental rotation on some comparison tasks. In contrast, linear regressions are both necessary and sufficient to infer mental tracking on the task used in experiment 1. Children were required to use mental tracking to continuously monitor the changing orientation of the pointer. Linear regressions would have been generated by a mental tracking strategy, unless tracking speeds varied inversely as a function of rotation time. This latter possibility was remote, since children had no advance knowledge about the time intervals for upcoming trials. Other possible explanations for non-linear distance x time functions -- e.g. children's failure to mentally note the pointer's imagined location at the time of the signal, or their failure to accurately point to the imagined location -- were ruled out by a pretest of children's proficiency at these responses on a set of "perceptual tracking" trials.

Third, the to-be-rotated stimulus in the present experiment could be effectively reduced to the simplest possible object -- a point. The task simply required children to keep track of the rotation of the pointer's tip, or any other point along its length. A Shepard-Metzler comparison task, in contrast, requires an object with component parts that can be the basis for same-different discriminations. Thus, the question of object complexity or familiarity enters into the interpretation of results from Shepard-Metzler tasks, but not from the task in the present experiment.

Seventy-six children from parochial elementary schools in New Orleans, Louisiana were tested. There were 26 kindergarteners (mean age, 5 years, 8 months), 30 second graders (mean age, 7 years, 9 months) and 20 fourth graders (mean age, 9 years, 8 months).

On the mental rotation trials in the experiment proper, children were required to think about the pointer rotating instead of seeing it rotate. In contrast to the speed estimation trials, children had no information at the beginning of each mental rotation trial about rotation distance or rotation time. They were simply told to think about the pointer rotating until they heard the experimenter's signal. As on pretest trials, their task was to point to the segment on the color wheel that marked the pointer's imagined location at the time of the signal. The experimenter instructed children to "Think about the pointer moving at the same speed as before (i.e. as on the speed estimation trials). When you hear me tap my pencil on the table, think about which color the pointer was on at that exact moment. Then show me the color by pointing to the board. When you're ready to start thinking about the pointer moving, push this black button. When you hear me tap, show me the color you imagined the pointer was on just at that moment."

There were four measures of children's performances in this experiment. First, the degrees of rotation indicated by each child for mental rotation trials at the five time intervals were analyzed by regression. These analyses designated children as "rotators" if regressions were significant at $p_s<.05$, or "non-rotators" if regressions were not significant.

Second, the percentages of children's "rotational" eye movement patterns were examined to determine whether or not they corroborated children's classifications as "rotators" or "non-rotators". Two measures of children's mental tracking efficiency were also analyzed. The first measure indicated the degree to which children's imagined rotation distances were linear (r^2) -- i.e. the proportions of variance accounted for by linearity in imagined distance x time functions. The second measure was the slopes(b) of children's distance x time functions which provided a direct estimate of children's mental tracking rates.

The regression and eye movement data supported the developmental trend described by Piagetian studies, but contradicted Marmor's claim that pre-schoolers are as proficient as older children at mental tracking. Second, children's variability scores on the speed estimation trials suggested that kindergartener's difficulty on the mental rotation trials cannot be attributed to their inability to estimate and maintain a temporal interval. Non-rotators in the kindergarten and second grades were as consistent in their estimations

of time intervals on the speed estimation trials as rotaters in those grades.

Third, analyses of children's r^2 values and rotation rates yielded no indication of quantitative improvements with age in children's mental tracking efficiency. This finding is counter to the results from Marmor's (1975; 1977) and Kail, Pelligrino and Carter's (1980) studies, which reported significant age differences in children's reaction-time function slopes on Shepard-Metzler type rotation tasks. However, since the Shepard-Metzler rotation task is ambiguous with respect to the strategies that generate linear reaction time functions, it is also ambiguous with respect to the meaning of these functions' parameters. Slopes may reflect mental rotation rates, or they may reflect children's perceptual comparison speeds. Slopes of a relatively small magnitude were interpreted in Marmor's and Kail et al's studies as evidence for fast rotation rates. An alternative interpretation could be that children made perceptual comparisons at relatively uniform speeds across orientations. Accordingly, age related slope differences could indicate that younger children need to spend more time comparing stimuli when orientation differences are large, in order to maintain high levels of accuracy in same-different judgments, whereas older children can make accurate comparisons quickly regardless of orientation differences. One study which did not find age related slope differences (Childs & Polich 1979) did not employ the Shepard-Metzler procedure but rather Cooper and Shepard's (1973) successive presentation procedure, which did not permit perceptual stimulus comparisons.

A second possible reason for the finding of no developmental differences in children's rotation rates in experiment 1 is that children were required to mentally track a point (the end of the pointer), as contrasted with the requirement to rotate an object or a letter of the alphabet in studies reporting rotation rate differences. The requirement to mentally rotate an object or an alphanumeric symbol may involve strategic processes that are unnecessary in mentally tracking a point, and which older children might carry out faster than younger children. A similar hypothesis concerning the relation between mental rotation strategies and rates was suggested by Kail et al. (1980) to account for their finding of a developmental rate increase. In this view, older and younger individuals might use different strategies to rotate an object, which require different amounts of time. For example, older individuals rotate only a distinctive part of an object, while younger individuals might rotate the whole object. Or, older individuals might rotate the whole object all at once, while younger individuals might might rotate each component separately. In either case, the strategy used by younger individuals might take longer than the strategy used by older individuals.

Kail et al.'s hypothesis of developmental changes in mental rotation strategies is consistent with the notion that different strategies place different demands on children's information-processing capacities, and that children become more adept with practice at carrying out information-processing routines, much as they become more adept at carrying out skilled motor routines. From the standpoint of Piagetian theory, however, there is less reason to predict age related differences in mental rotation strategies. In this view, mental rotation images are symbolic representations of spatial operations, which are coordinated mental actions that underlie deductive reasoning about spatial relations. For example, spatial operations subdivide space into intervals, coordinate spatial intervals within coordinate axis reference systems, and change the positions of objects in relation to reference frames (Piaget, Inhelder & Szeminska 1960).

Children can make inferences about the relative amounts of distance an object might travel during different intervals of time, or inferences about the locations of one part of an object from knowledge of the location of another part, on the basis of spatial placement and displacement operations. Theoretically, once a child is capable of spatial operational logic, he (she) should be able to represent these operations in mental imagery in a variety of ways. Children might choose to mentally displace one part of an object, and then make post hoc deductions about the remaining parts' positions and orientations, or to displace all parts of an object simultaneously by an on-going deductive reasoning process, represented symbolically in imagery by a holistic strategy. Either approach would be within children's logical capabilities, and the choice would reflect task demands or individual preference.

Experiment 2 in the study, therefore, addressed three questions. The first was whether developmental differences in children's mental tracking rates would emerge if children were required to track a whole object, rather than a single point. This question stemmed from the findings that different aged children mentally tracked at equivalent rates in experiment 1 in this study, in which the to-be-tracked object could be reduced to a point, but at different rates in some experiments in which children were required to rotate whole objects. The question was addressed by modifying the pointer used in experiment 1 so that it rotated around its mid-point, and by distinctively marking the pointer's two ends. Children were required to identify the imagined location of one or the other of the pointer's ends on each trial, but were not told in advance of the signal which end would be indicated. Thus, a strategy was called for that could keep track of the rotation of both ends of the pointer.

The second and third questions, suggested by Kail et al.'s speculations, were whether or not children at different age levels use different strategies to mentally track the rotation of the pointer's two ends, and whether or not children's tracking rates vary as a function of their strategies. Two basis strategies were differentiated on the basis of children's response time patterns. Response time on the task used in experiment 2 was the interval between the presentation of the signal indicating that children were to note the imagined location of the pointer's designated end, and children's depression of a reaction-time button corresponding to the color on the backdrop that marked the pointer's imagined location. If response times differed as a function of the pointer's designated end, it was assumed that children had mentally tracked one end of the pointer on all trials, but then looked 180° across the backdrop for the location of the opposite end on trials when that end was named. If response times did not differ as a function of the pointer's designated end, but were distinctly bimodal, it was assumed that children alternated between tracking one end on some trials, and the other end on other trials, thus generating short times when the tracked end was named, but longer times when the untracked end was named. If response times did not differ as a function of the pointer's designated end and were unimodal, it was assumed that children had tracked both ends of the pointer simultaneously. Thus, response time patterns differentiated "end-to-end" and "end-to-end alternating" strategies, on the one hand, from "holistic" (or both end) strategies, on the other hand.

One hundred and five children from four grades (1,3,5, and 8) were tested -- 25 from grade 1 (11 males and 14 females), 26 from grade 3 (14 males and 12 females), 27 from grade 5(10 males, 17 females, and 27 from grade 8 (12 males and 15 females). Mean ages (in years and months) of children in the four grades were 6-7 for the first graders, 8-5 for third graders, 10-7 for fifth graders, and 13-9 for eighth graders. The children in the three younger grades were attending parochial elementary schools in New Orleans, Louisiana. The eighth graders were attending a public junior high school. Both schools served a middle to lower middle class population

All three questions asked in this experiment answered negatively by the results. First, no developmental differences in rotation rates were observed, despite the requirement for children to imagine the rotation of a whole object. This requirement did, however, result in considerably slower rotation times relative to those observed in experiment 1 for children at all ages. End-to-end rotaters may have deliberately slowed their speeds in anticipation of trials on which they would have to deduce the position of the untracked end. Holistic rotaters speeds may have been slowed by the requirement to coordinate the position of the pointer's two ends after each imagined position change.

Second, no developmental differences in mental tracking strategies were observed among children who were able to imagine the rotation of the whole pointer. The finding that mental trackers at each of the three higher grade levels were capable of both end-to-end and holistic strategies fits with Piaget and Inhelder's supposition that spatial operations underlie rotation images, and can be manifested by a variety of different strategies. Logically, both the end-to-end and holistic strategies require children to imagine changes of position for one or more parts of the rotating object, and both require children at some point either during or after the imagined rotation to deduce the position of one end of the pointer from the other. Thus, children who can reason deductively about space and spatial movements should possess the prerequisite logical ability to formulate and execute either a holistic or an end-to-end strategy. The finding that children younger than 8 years of age in this experiment were unable to use either strategy fits with Piaget's observation that children develop the capability to make inferences regarding space and other domains at approximately age 7 or older (e.g. Piaget, Inhelder & Szeminska 1960).

There were, however, significant within grade differences in the frequencies of end-to-end and holistic strategy users. This difference could be explained by differences in the two strategies' information processing demands. Specifically, the end-to-end strategy seems to require less effort than the holistic strategy. The holistic strategy requires ongoing coordination of the positions of the two extremities of the pointer, while the end-to-end strategy requires a single deduction of one end's position from the other. Further, an end-to-end strategy may have been suggested by the straight-line relationship between the pointer's two ends. Children may have recognized the feasibility of deducing one end's position

from the other at the time of the signal, and thus chosen the path of least effort during the actual rotation phase. If the parts of the to-be-rotated object had been more complexly related, more children may have attempted holistic strategies than part-to-part strategies, and a different developmental trend may have been observed.

Third, rotation rates were not a function of mental rotation strategies. Rates for holistic, end-to-end, and one-end rotaters were highly comparable. As previously speculated, rates for both holistic and end-to-end strategy users may have been slowed by the requirement to keep track of both ends of the pointer. For holistic strategy users, this doordination was an on-going process. For end-to-end and one-end rotaters, the anticipation of having to locate the untracked end may have slowed their rates.

The results of these two experiments are not consistent with Marmor's findings that pre-schoolers can mentally rotate, nor with the information-processing theoretical point of view that mental rotation is a learned routine that becomes more efficient with practice. Children younger than 7 did not generate linearly increasing distance time functions, rotation rates were equivalent among rotaters at different ages, and whole pointer rotater strategies (end-to-end v.s Haldistic) that intuitively differed in their information-processing demands were not used as a function of children's ages. Equivalent rotation rates and rotation strategies in these experiments may reflect specific task demands. For example, there may be an optimal rate for mentally tracking an object with the intent of identifying its location at any given point in time, which children of all ages in these experiments spontaneously chose. Similarly, the characteristics of the object in experiment 2 may have narrowed the range of appropriate strategies to two that children at all ages could perform, while the use of more complex objects may have generated a wider, and more age-related, range of strategies.

In contrast, the failure of 5 and 6 year old children to generate linear regressions is less readily explained by task demands. On pre-tests, these children demonstrated an understanding of task objectives and procedures, and the ability to accurately note and point to the pointer's location on the backdrop. The only additional requirement in the experiments proper was to mentally, rather than perceptually, track the pointer. The to-be-tracked object in experiment 1 was reduced to the simplest form -- a single point. Thus, nonlinear regressions can reasonably be interpreted as a failure to mentally track. The discrepancy between these and Marmor's findings suggests either that linear trends in Marmor's studies reflected non-rational processes, or that mental tracking, as explicity required in this study, is a process that differs qualitatively from the kinetic imagery that children used on Marmor's tasks. In the present study, children were required to continuously monitor the pointer's rotation, while in Marmor's tasks, children were required to imagine the appearance of the rotated object only in the rotation's end-state. In the literature, however, researchers have been quite explicit in interpreting linear regressions on Shepard-Metzler tasks as evidence for a mental tracking process, in which images pass through a series of consecutively ordered states (e.g. Shepard & Metzler 1971). If mental tracking does not characterize the kinetic imagery process presumably used by pre-schoolers on Marmor's tasks, then more detailed study of that process is clearly needed.

IV. Children's spontaneous transformational imagery and memory for figurative states.

Piagetian imagery research to date has not attempted to establish the relevance of children's abilities to imaginally transform object states for other areas of their cognitive functioning. One area in which imaginal transforming of object states has been assumed to be important is that of children's memory. The constructivist approach to memory (e.g., Bartlett 1932; Piaget & Inhelder 1973) assumes that the ways in which people understand an experience influence the ways in which the event is remembered. Conceiving of an object state in terms of a network of potential changes or transformations presumably bestows greater significance, a deeper level of understanding, than conceiving of it exclusively in terms of figurative properties. The actual significance of the constructivist position for children's memory rests on the extent to which children spontaneously use transforming strategies when processing figurative states.

The experimental paradigm best suited for the investigation of the spontaneous generation of transformational imagery and its effect on memory is one in which (a) initial instructions leave open the nature of the processing to be performed on stimuli; (b) children are naive during the processing phase regarding the eventual requirement to recall the stimuli; and (c) independent measures of children's initial processing strategies and memory for the stimuli are included.

Reviews of the developmental memory literature (Liben 1977, Paris 1978) indicate that few, if any, existing studies meet all three requirements. Studies in which no initial processing specifications are included generally inform children that their eventual task is to remember the stimuli, and fail to include independent measures of initial processing strategies and memory performances (e.g., Paris & Upton 1976; Paris & Lindauer, 1976). Studies in which children are naive regarding the type of initial stimulus processing - e.g. to construct a story about the stimulus (Paris, Lindauer, & Cox 1977); to imitate the actions described in sentences (Paris & Lindauer 1976); or to copy the stimulus in a drawing (Furth, Ross & Youniss 1974; Piaget & Inhelder 1973). In these studies, opportunities were lost for measuring children's spontaneous processing of stimuli, and the value of relating measures of processing strategies to recall performances thereby reduced.

One objective of the present study was to determine whether children mentally transform object states on tasks in which particular processing strategies are unspecified. A second objective will be to examine the effect of transforming strategies on short and long term memory for figurative states.

Forty children in each of two grades--first and fourth--participated in the study. First grade subjects had a mean age of 6.27. Fourth grade subjects had a mean age of 9.26. All children were chosen from middle class Jefferson Parish Schools near New Orleans, La.

Children veiwed 55 cm by 35 poster boards with three horizontal lines labeled #1, #2. and #3. Poster boards having only one experimenter constructed state which was located above line #2, and leaving the spaces above line #1 and line #3 empty belong to the static one-state condition. For a complete list of the static one-state condition of each task, see Appendix 1. Boards having experimenter constructed states above line #1 and line #2 and leaving the space above line #3 empty belong to the two-state conditions. For a complete listing of tasks in the logical two-state and the illogical two-state conditions, see Sppendices II and III. On the logical two-state conditions an action implied in state #1 is continued in state #2. For instance, a stick tilted at 15° in relation to an upright stick in state #1 is tilted at 45° in state #2.

State #2 on the logical two-state and the static one-state conditions are identical. State #1 on the logical two-state and the illogical two-state conditions are identical. However, as illustrated in Appendix III, state #2 on the illogical two-state condition did not continue the action implied in state #1. In the example cited above, instead of a continuing increase in the distance between the two sticks, the position of the pivot was altered. This suggested no logical and on-going relationship between the two states, thus, the task is classified as illogical.

To insure that all tasks included in the illogical condition were indeed illogical, a pilot study was conducted. All tasks were given under each condition to 10 adults, 10 first graders, and 10 fourth graders. Failure by all 10 in each age group to discover an on-going relationship between the two states presented on tasks considered illogical was the criterion for tasks to be labeled illogical.

States on the 15 state construction tasks implied simple spatial transformations such as figure completions, rotations, enlargements, transpositions, and shape transformations. The figurative aspects of each of the tasks were distinct. Stimuli depicting sticks falling, circles turning, squares transposing, triangels rotating, clay elongating, etc., were employed so as to reduce or inhibit interference at the memory phase of the study.

Children were provided with all materials necessary to duplicare the states presented in Appendices I, II, and III as well as those necessary to complete or to transform the state(s) in some manner.

In the processing phase, a total of 15 tasks were administered individually to each child. One-third of these tasks were administered under each of the following three conditions: (a) static one-state; (b) logical two-state; and (c) illogical two-state. Consequently, each child was required to answer five tasks from each of the three conditions. Random assignment of specific tasks to conditions was made with the restriction that at each grade level each task was administered under each condition an equal number of times. A second restriction was that the first two tasks administered to each child were among the least difficult tasks included in the study. The relative difficulty of tasks was determined by the pilot study. In determining relative difficulty fo the tasks, transformation performance on logical tasks in the pilot study was considered. Tasks which were transformed the greatest proportion of the time were considered least difficult.

Ten children at each grade level received their first task in the static one-state condition, 10 received their first task in the logical two-state condition, and 10 received their first task in the illogical two-state condition. Regardless of the initial task condition, all children received a static condition task second. The reason for this ordering was to determine whether performance on the static task could be affected by the condition of the initial task encountered by children. It was expected that if logical two-state tasks have a "cueing" effect, transformations should be made more often on static tasks following the logical two-state than those following the other two conditions. The condition order of the remaining tasks was such that each condition followed each type of condition approximately the same number of times. That is, static followed static, static followed logical, static followed logical, static followed illogical, etc., approximately the same number of times at each age level.

A poster board, like the one shown in Figure 1, having three lines but depicting no states was presented to the child with the following verbal instructions:

> "For each of the following tasks, I'm going to show you a board just like this one. All of the boards will have three lines just like the one in front of you. But, on some of the boards I will have already built something on the first and on the middle lines. On other boards, I will have already built something on only the middle line. After looking at what I built, I will ask you to build something on the empty line or lines that goes best with what I have already built. On every board the state on the line #1 comes first, on line #2 comes second, and on line #3 comes last."

The 15 poster boards were then presented one at a time, corresponding to the 15 different tasks. After each, the child was asked to construct the state(s) that "go best" with the one(s) already depicted. In each instance, the numerical order of the states was emphasized. On each of the two-state condition tasks children were told:

> "I built this one (pointing to line #1) first, then I built this one (pointing to line #2), which follows next after the one I built on line #1. Now, you build one that goes best last after these two that I built."

On each of the one-state condition tasks children were told:

> "I built this one (pointing to line #2) that goes in the middle. Now, you build one here (pointing to line #1) that goes first, before the one I built. And, build one here (pointing to line #3) that goes best last, after the one I built."

After the child's constructions on each board were completed, he was asked to explain why the states he constructed "went best" with the states already depicted.

Children's constructions on the processing phase of the experiment were scored as "transformational or non transformational" by three independent raters. Inter-rater reliability was 96.8%. Constructions scored transformational continued the same action throughout all the states of a given task. When no on-going action was implied by a child's construction, it was scored non-transformational. Constructions scored transformational which also encompassed all relevant aspects of the state(s) presented were recorded as strict transformations. Constructions scored transformational which did not take into account a-l relevant aspects of the state(s) presented, but indeed depicting a transformation, were recorded as loose transformations. Figure 2 is an accurate example of the differences between these two. Constructions that were strict transformational depicted size as well as numerical progression from #1 to state #3. Loose transformational constructions depicted only a numerical progression and ignored the equally relevant increase in size from state #1 to state #3. The need for this dual scoring presented itself when some of the transformational constructions produced by the children were transformations by definition but were not the transformations the states presented should have elicited. Therefore, each child was assigned two scores, one reflecting his number of "strict transformational" performances.

Immediately following the processing phase was the short-term memory phase of the study. Following the same order of presentation as in the processing phase, each task was represented to the child but with this modification: the child was given the state(s) he constructed during the processing phase of the study and asked to produce the experimenter-constructed state(s).

The final portion of the study was the long-term memory phase. All procedures were identical to the short-term memory phase, except they took place one week later.

Memory, like performance, was also scored in a dual fashion. Strict transformational memory performance was scored "correct" if all states presented to the child within the confines of a given task (one state on the static one-state and two states on the two-state conditions) were accurately reproduced on tasks on which children made strict transformations. Memory performance was scored "correct" or tasks on which children made "loose transformations" if all states presented to the subject within the confines of a given task were accurately reproduced regarding the aspects of the stimuli encompassed in the transformation. Figure 3 gives examples of responses scored "correct" for each of the two transformational categories. Since strict transformations encompassed all aspects of the stimuli, all aspects must be reproduced for a correct score on the memory phase. However, loose transformational responses included only the numerical aspect of the stimuli. Therefore, only those aspects of the stimuli implied by the transformation, i.e., the number presented in each of the states must be reproduced for a correct score on the memory phase.

The study revealed a significant difference in transforming performance by first and fourth graders. More fourth graders than first graders predominantly used transforming strategies on static and logical tasks. Also, fourth graders transformed a greater number of tasks than first graders. This was expected since according to Piaget, children at these two ages are functioning at two different cognitive levels. First graders tend to function at the concrete operational level while fourth graders tend to function at the formal operational level.

A significant condition effect was also apparent. Children at both grades made significantly more transformations on logical than on static tasks and significantly more transformations on static than on illogical tasks. This was in accord with the results of research conducted by Kreutzer, Leonard, and Flavell (1975) and by Brown and Barclay (1976) which indicated that children are often capable of utilizing processing strategies which they do not spontaneously employ. The "cue" inherently implied in the logical tasks induced the children to employ transforming strategies that they did not use spontaneously on static tasks. This accounts for the significantly greater number of transformed logical tasks as compared to the static.

Cuing affected transforming performance in both first and fourth graders. However, fourth graders tended to benefit more by the "cue" implied on logical tasks. Fourth graders used more transforming strategies on logical than on static tasks. This significant difference was not apparent in first graders. This indicates that cueing was more effective for fourth graders than for first graders. Perhaps it is because they were more able to perceive the implied cue since they were more developmentally advanced.

When children were not able to transform, the strategies employed by both grades were very diverse. First and fourth graders both sought to construct states which were in some way related to the states presented to them for each task such as changes in the orientation or in the parts which made up the states involved or some combination of the states presented. No differences were apparent between the type of responses given by the children in the different grade levels.

Comparisons of memory performance revealed that fourth graders remembered significantly more tasks than first graders. Upon closer inspection, however, it was determined that memory differences existed only on tasks which could be transformed, i.e., logical and static tasks. On illogical tasks (those which did not permit the use of transforming strategies) no memory differences between first and fourth graders were revealed. Fourth graders made significantly more transformations than first graders, and they remembered a greater number of tasks but only in conditions where transformations were possible. This offers direct support for the hypothesis that transforming as a strategy increases memory of individual states. Further, when the initial processing strategy was controlled (transforming versus non-transforming) no condition differences between the memory of static and of logical tasks by first or fourth grade children were revealed. Since the amount of figurative information to be remembered in these two conditions was not equivalent, this finding also supports the hypothesis that transforming is a strategy that increases memory performance.

Clearly, transforming as a strategy has a significant memory effect. However, this study also indicated some other factors which affected memory performance. There was a difference between long and short term memory performance for first graders on transformed tasks. This difference was not revealed in fourth grade memory performance. There was also a difference between first and fourth graders long term memory scores on transformed tasks. Both of these differences might be explained by the fact that there was very little variability in transformation scores of first graders, who quite often made only one transformation.

Also, short term memory performance of first and fourth graders differed significantly on non-transformed tasks. This difference can be attributed to the amount of information to be remembered. Apparently, fourth graders are capable of remembering, for a short period of time and without the aid of transforming strategies, the amount of figurative information presented. Without using transforming strategies, this same amount of figurative information cannot be retained by first graders. Consequently, a difference in short term memory of non-transformed tasks between the two grades was revealed. This difference did not exist in long term memory performance because memory of figurative information when transforming strategies was not involved was not long lasting.

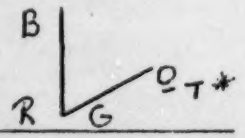
Explaining why a particular response was appropriate also significantly affected memory performance. Both first and fourth graders remembered significantly more non-transformed tasks that were explained than non-transformed tasks that were not explained. When the effects of explaining were compared to the effects of transforming, however, it was revealed that explaining was not clearly as effective as transforming. Non-explained transformed tasks were remembered significantly more often than explained non-transformed tasks. Thus, transforming as a strategy is more effective than the strategy of explaining.

Memory appears to be influenced not predominantly by the bulk of the material to be remembered but by the manner in which the individual relates the material, i.e., the processing strategy he is able to utilize in connection with the material. Age is a factor which influences both the processing strategies available to the individual and the ability to remember an absolute amount of material. However, at any age some transformational strategies are available, and when they are employed, the amount of figurative material that must be remembered is in some way lessened. Further research in this area would prove beneficial to today's educational system. Finding methods to utilize transforming strategies within the realms of education should lead to faster and longer lasting acquisitions of knowledge.

APPENDIX I

Tasks in Static Condition

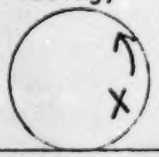
Task 1 - Falling Sticks (craft sticks, one colored red & blue and one colored orange & green)



Task 2 - Size Progression (pink strips made out of construction paper)

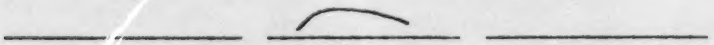
Task 3 - Running People (orange & green running figures; arrows indicate the direction figures are facing)

Task 4 - Crawling Snails (red circles with blue snails; arrows indicate direction snail is facing)

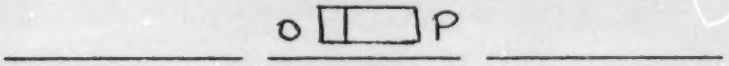


Task 5 - Figure Completion (red strips made out of construction paper)

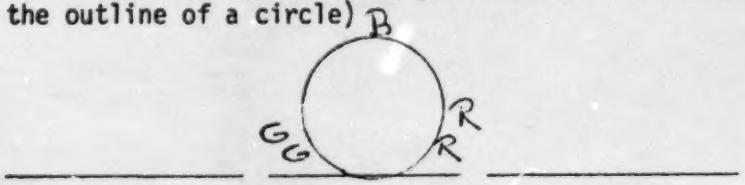
Task 6 - Arcs (yellow pipe cleaners)



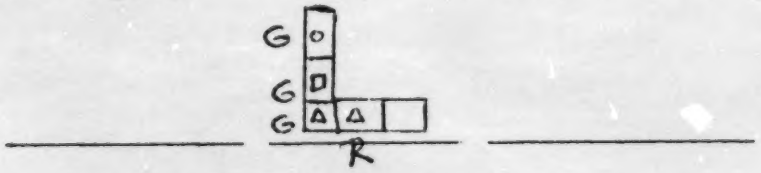
Task 7 - Sliding Sauares (orange & purple squares)



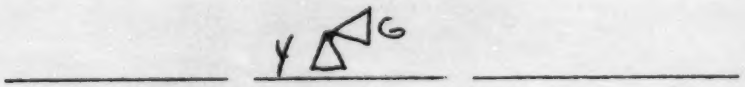
Task 8 - Circle Location (small red, green & blue circles placed around the outline of a circle)



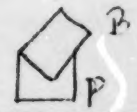
Task 9 - Class Inclusion (green, red & yellow colored circles, squares & triangles)



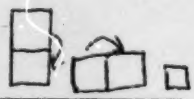
Task 10 - Rotating Triangles (yellow & green triangles and blue pivots)



Task 11 - Rotating Squares (pink & blue squares with yellow pivots)



Task 12 - Paper Folding (sheet of white paper 81/2 by 11 inches)



Task 13 - Rotating Cube (each of the six sides of the cube painted a different color)

Task 14 - Peg Board (red pegs, blue pegs, and a rubber band)

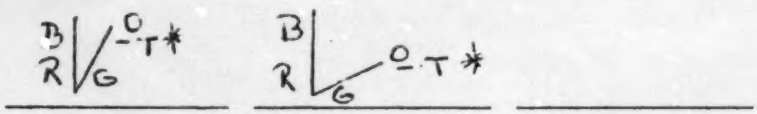
Task 15 - Clay (blue clay)

* Top--The so designated part of the figure lies on top at the point of intersection.

APPENDIX II

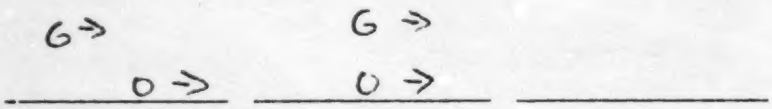
Tasks in Logical Condition

Task 1 - Falling Sticks (craft sticks, one colored red & blue and one colored orange & green)

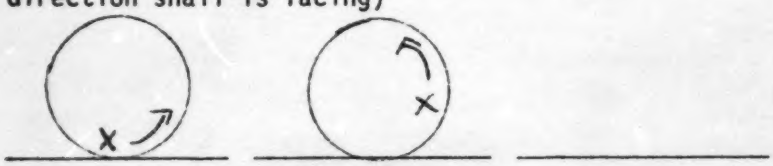


Task 2 - Size Progression (pink strips made out of construction paper)

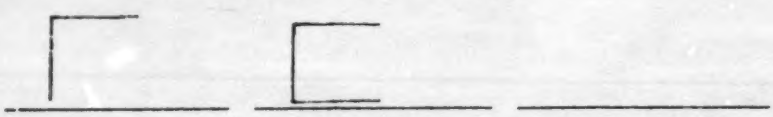
Task 3 - Running People (orange & green running figures; arrows indicate the direction figures are facing)



Task 4 - Crawling Snails (red circles with blue snails; arrows indicate direction snail is facing)

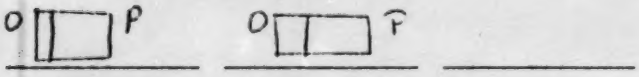


Task 5 - Figure Completion (red strips made out of construction paper)

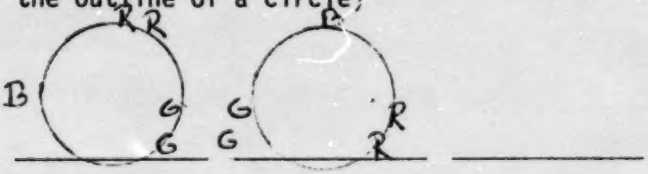


Task 6 - Arcs (yellow pipe cleaners)

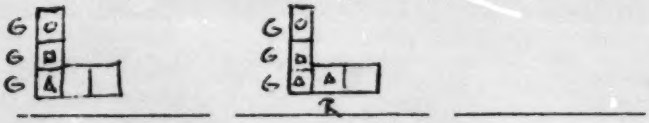
Task 7 - Sliding Squares (orange & purple squares & triangles)



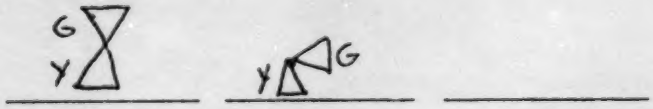
Task 8 - Circle Location (small red, green & blue circles placed around the outline of a circle)



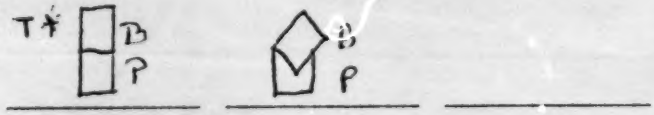
Task 9 - Class Inclusion (green, red & yellow colored circles, squares, & triangles)



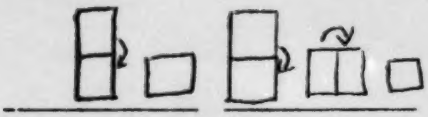
Task 10- Rotating Triangles (yellow & green triangles and blue pivots)



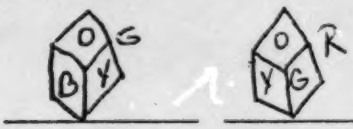
Task 11- Rotating Squares (pink & blue squares with yellow pivots)



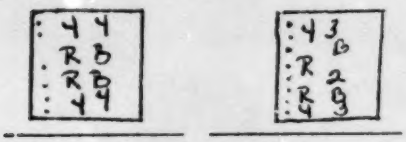
Task 12- Paper Folding (sheet of white paper 8 1/2 by 11 inches)



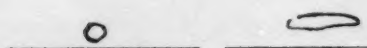
Task 13- Rotating Cube (each of the six sides of the cube painted a different color)



Task 14- Peg Board (red pegs, blue pegs, and a rubber band)



Task 15- Clay (blue clay)

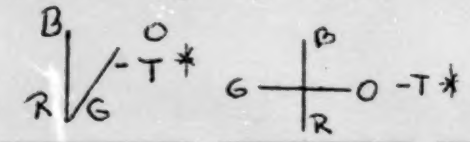


* Top--The so designated part of the figure lies on top at the point of intersection.

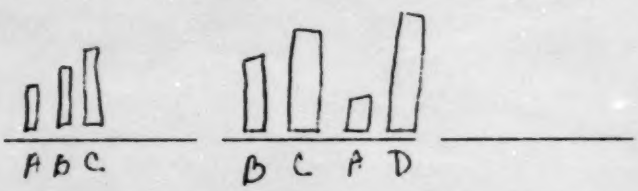
APPENDIX III

Tasks in Illogical Condition

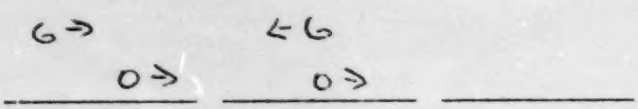
Task 1 - Falling Sticks (craft sticks, one colored red & blue and one colored orange & green)



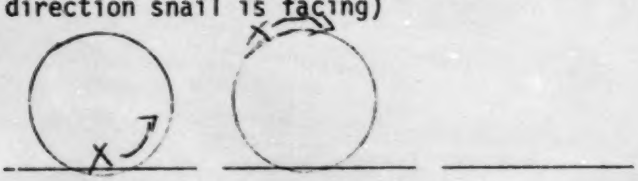
Task 2 - Size Progression (pink strips made out of construction paper)



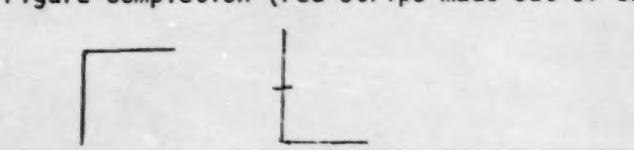
Task 3 - Running People (orange & green running fugures; arrwos indicate the direction figures are facing)



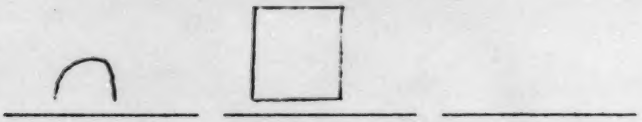
Task 4 - Crawling Snails (red circles with blue snails; arrows indicate direction snail is facing)



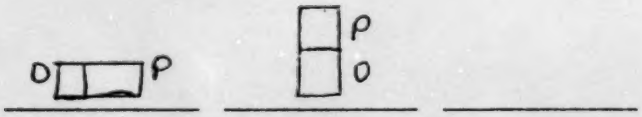
Task 5 - Figure Completion (red strips made out of construction paper)



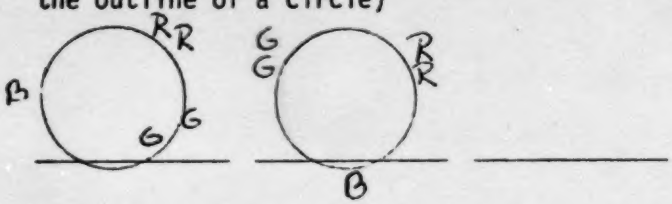
Task 6 - Arcs (yellow pipe cleaners)



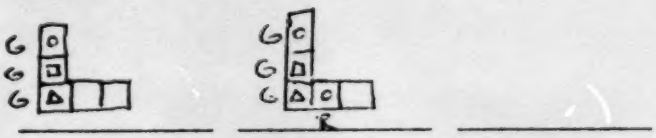
Task 7 - Sliding Squares (orange & purple squares)



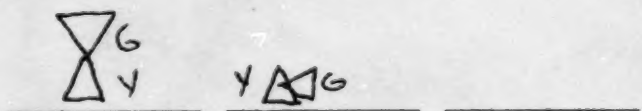
Task 8 - Circle Location (samll red, green & blue circles placed around the outline of a circle)



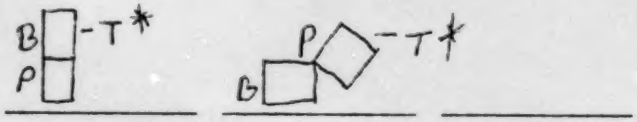
Task 9 - Class Inclusion (green, red & yellow colored circles, squares & triangles)



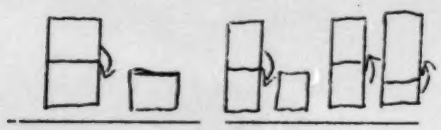
Task 10- Rotating Triangles (yellow & green triangles and blue pivots)



Task 11 - Rotating Squares (pink & blue squares with yellow pivots)

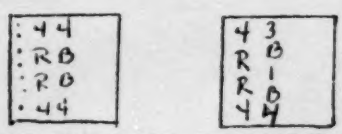


Task 12 - Paper Folding (sheet of white paper 8 1/2 by 11 inches)

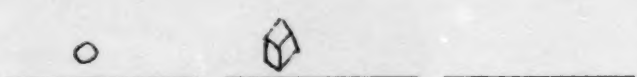


Task 13 - Rotating Cube (each of the six sides of the cube painted a different color)

Task 14 - Peg Board (red pegs, blue pegs, and a rubber band)



Task 15 - Clay (blue clay)



* Top-The so designated part of the figure lies on top at the point of intersection.

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Manuscripts generated under grant
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